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(54) **ESD PROTECTION DEVICE**

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(22) Filed: **Aug. 9, 2012**

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Feb. 15, 2010 (JP) 2010-030743

(51) **Int. Cl.**
H01C 7/10 (2006.01)

(52) **U.S. Cl.**
USPC **338/21**; 338/13

(58) **Field of Classification Search**
USPC 338/21
See application file for complete search history.

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(57) **ABSTRACT**

An ESD protection device includes a ceramic multilayer substrate in which a plurality of ceramic insulating layers are laminated; a first connecting conductor extending through the main surfaces of the insulating layer; a mixture portion extending along a main surface of the insulating layer including the first connecting conductor and connected to the first connecting conductor, the mixture portion including a material dispersed therein, the material including at least one selected from a metal and a semiconductor, a metal and a ceramic, a semiconductor and a ceramic, a semiconductor, and a metal coated with an inorganic material; and a second connecting conductor that has electrical conductivity and is connected to the mixture portion and extends along the main surface of the insulating layer on which the mixture portion is provided.

14 Claims, 11 Drawing Sheets

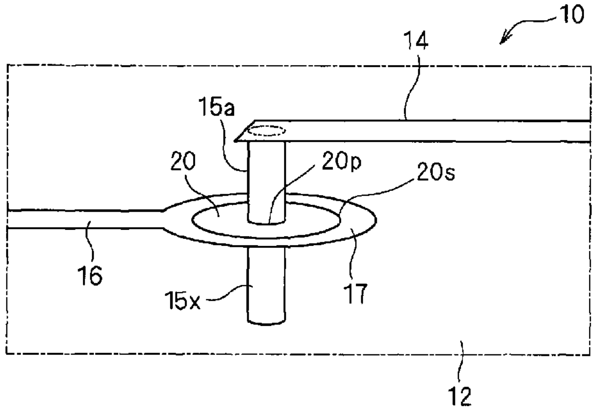


FIG. 1

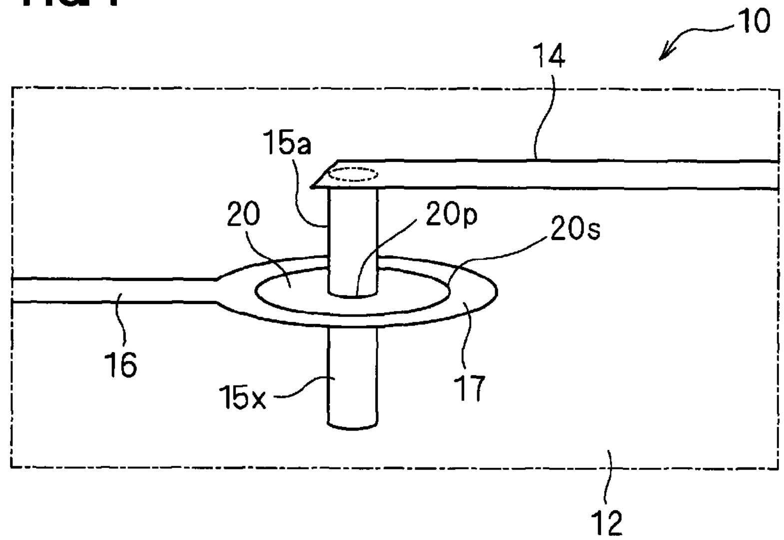

10
14
15a
20
20p
20s
16
15x
17
12

FIG. 2

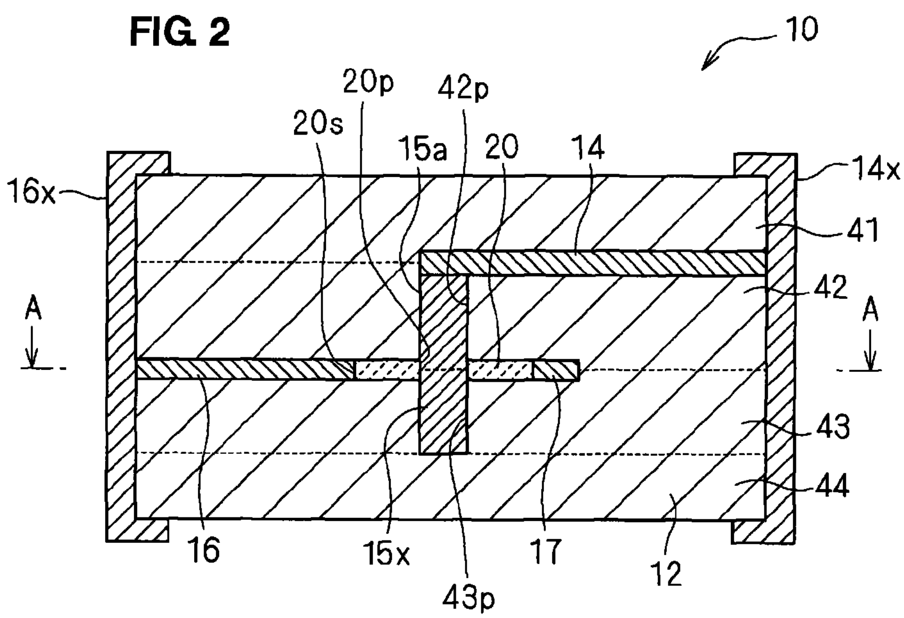

10
20p
42p
20s
15a
20
14
16x
14x
41
42
A
A
43
44
16
15x
17
12
43p

FIG. 3

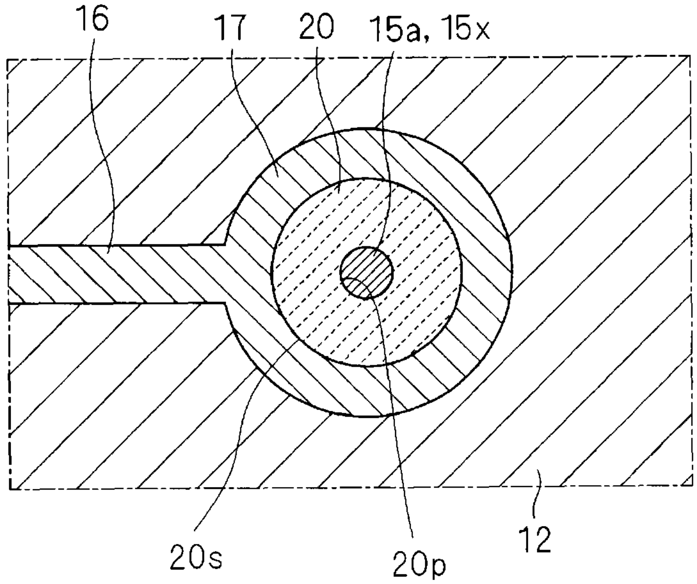

16
17
20
15a, 15x
20s
20p
12

FIG. 4

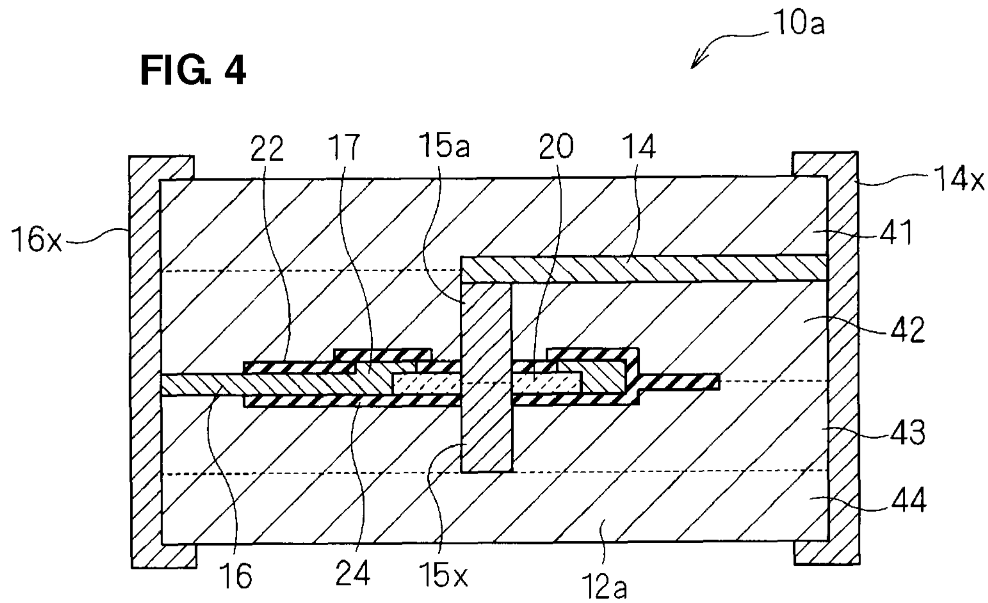

10a
22
17
15a
20
14
14x
16x
41
42
43
44
16
24
15x
12a

FIG. 5A

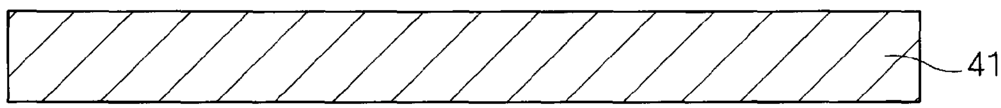


FIG. 5B

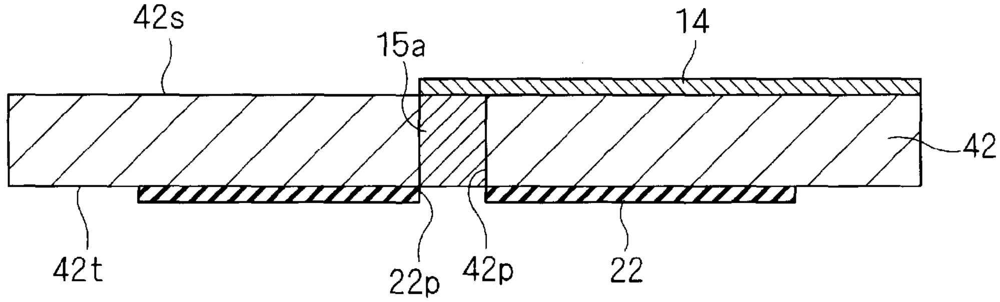


FIG. 5C

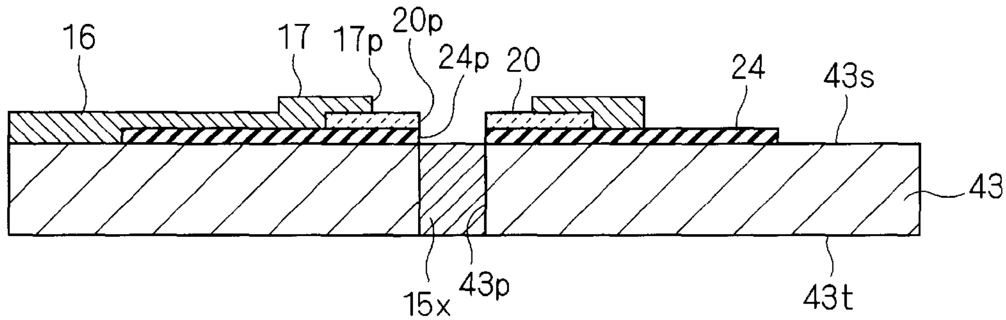


FIG. 5D

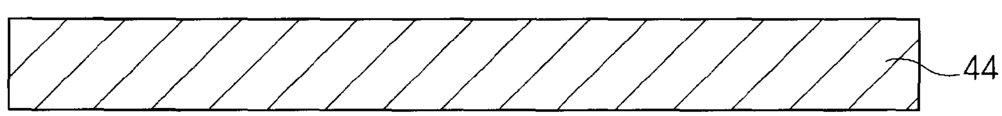


FIG. 6

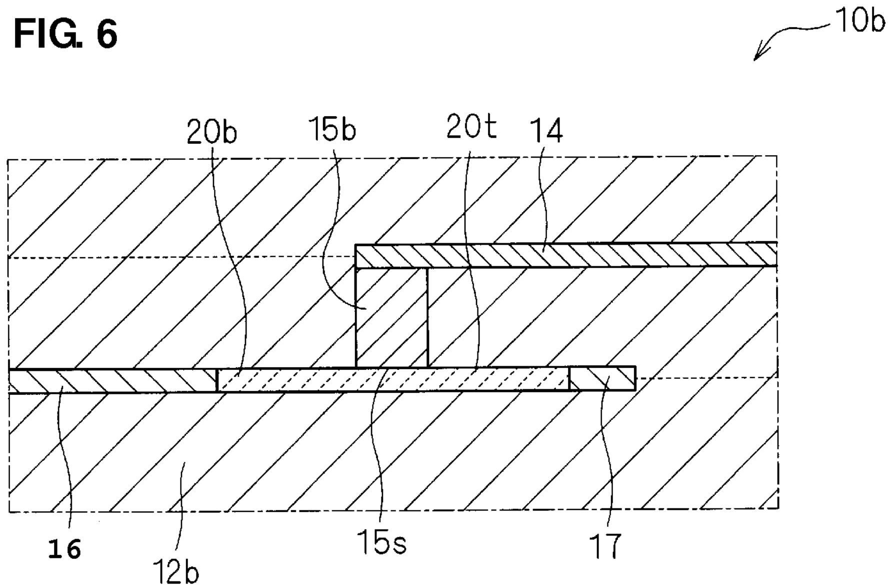

10b
20b
15b
20t
14
16
12b
15s
17

FIG. 7

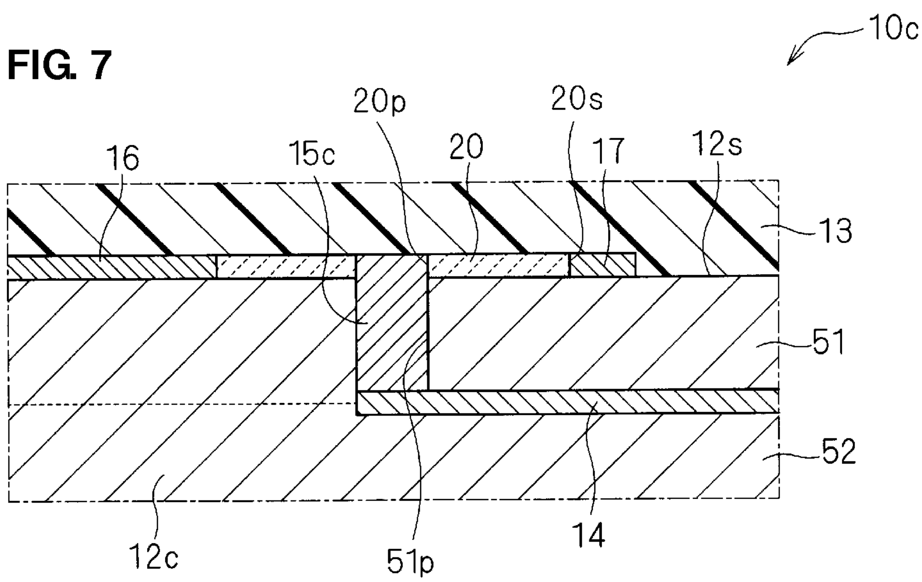
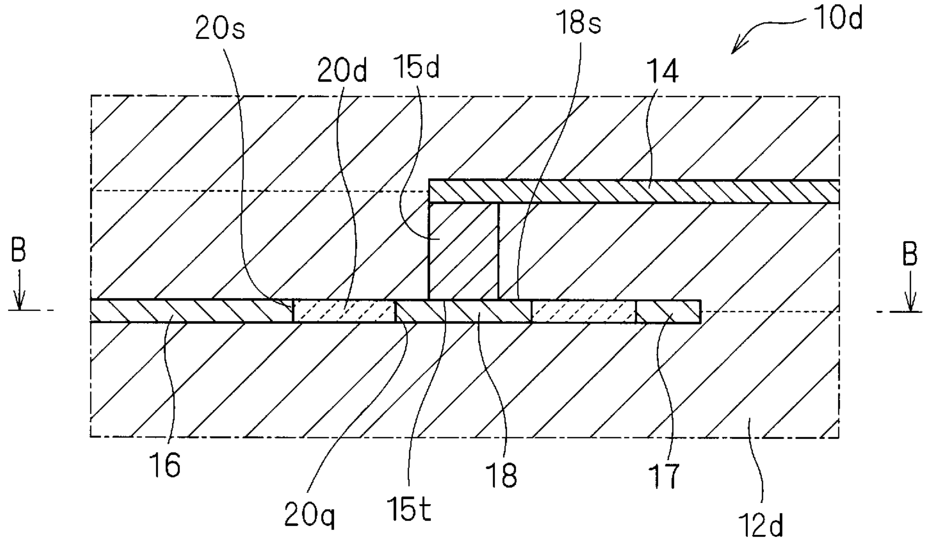
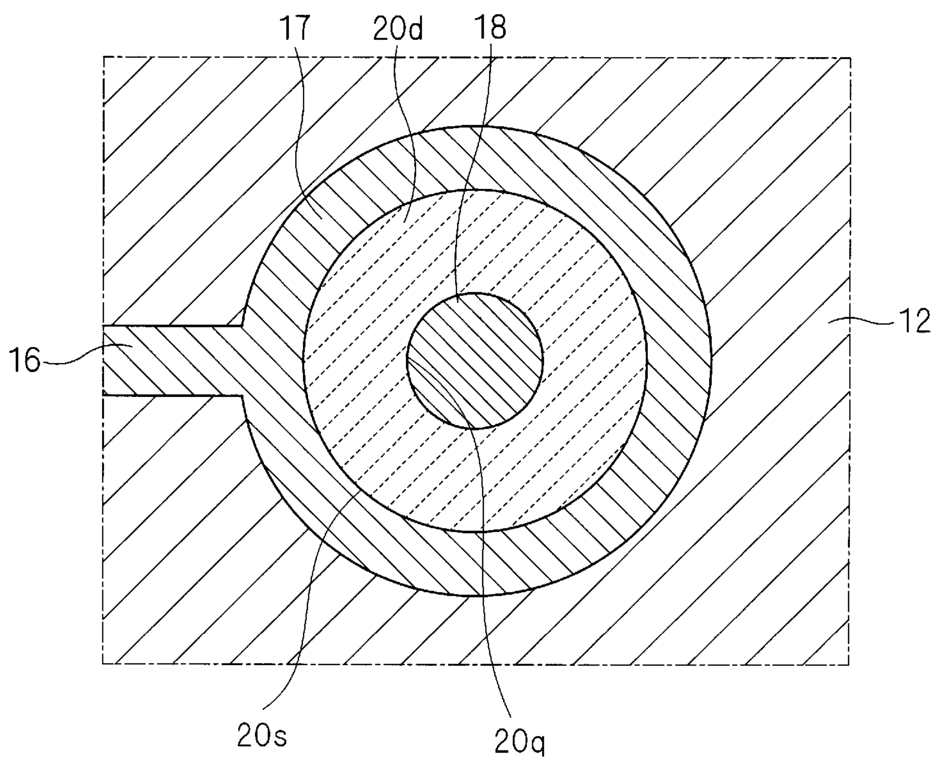

10c
20p
20s
16
15c
20
17
12s
13
51
52
12c
51p
14

FIG. 8A



10d
20s
20d
15d
18s
14
B
B
16
20q
15t
18
17
12d

FIG. 8B



17
20d
18
16
12
20s
20q

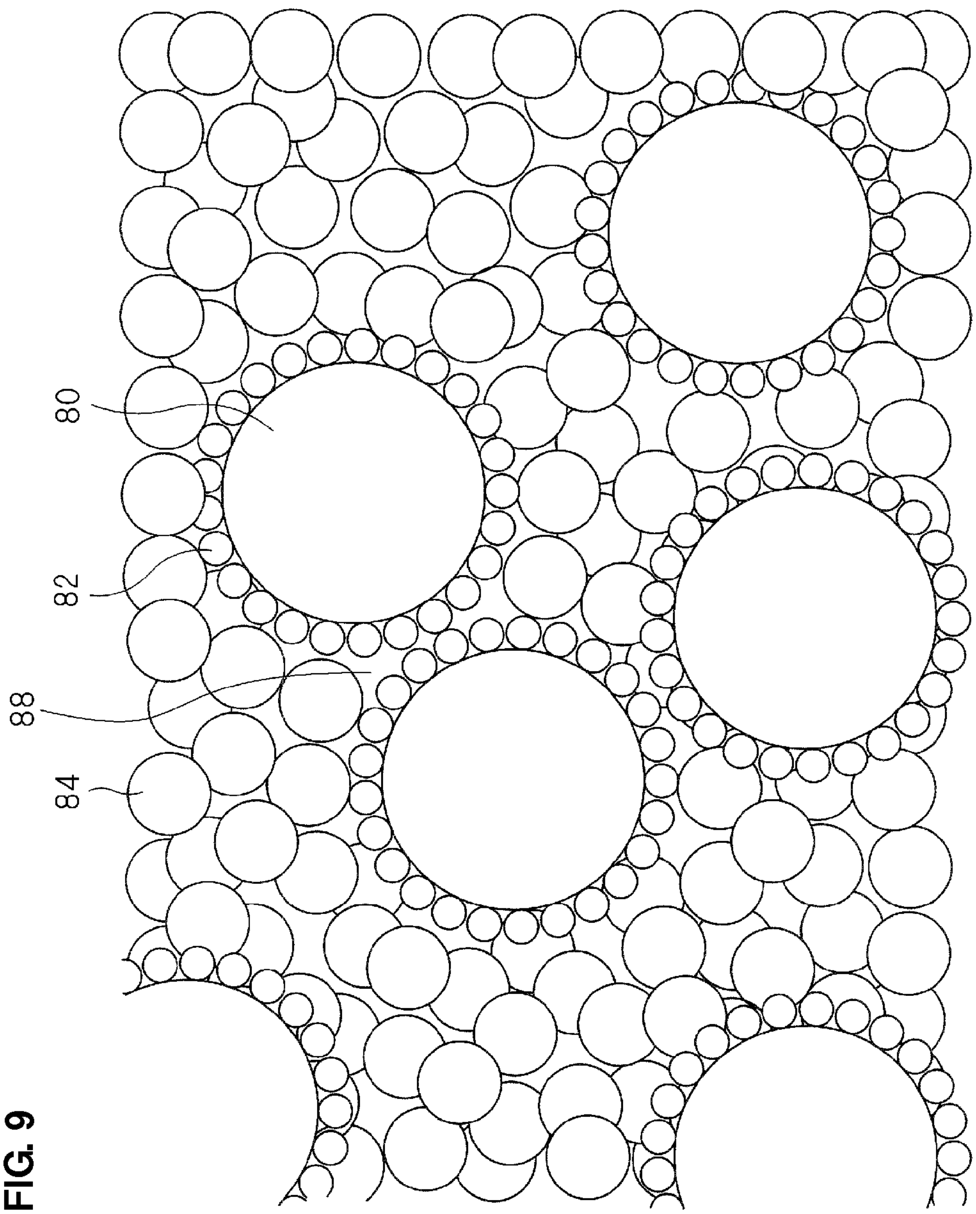


FIG. 9

FIG. 10

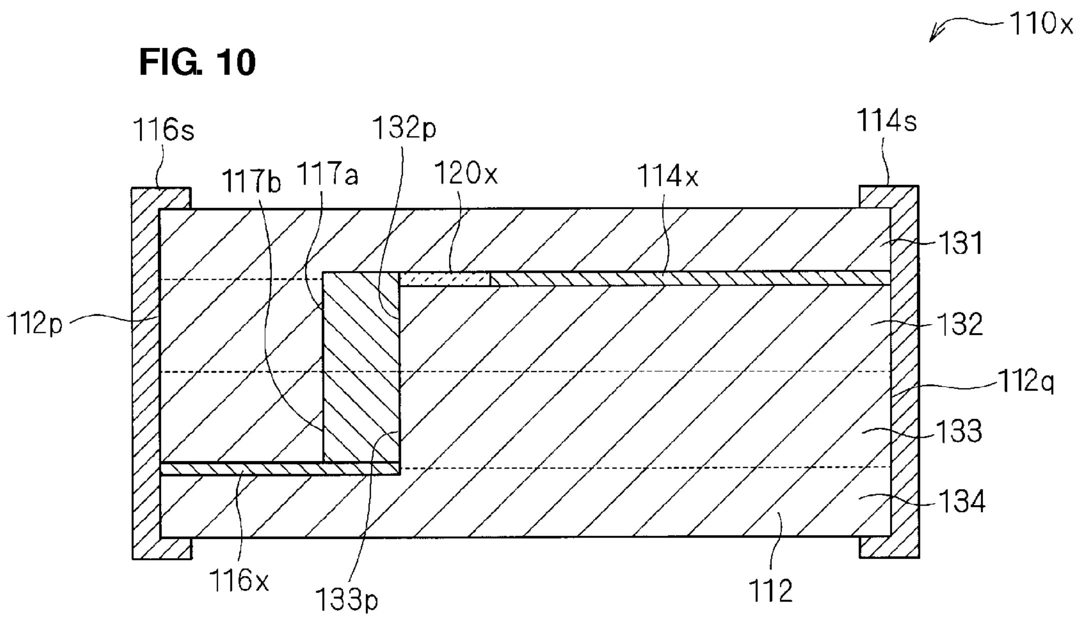

110x
116s
132p
114s
117b
117a
120x
114x
131
112p
132
112q
133
134
116x
133p
112

FIG. 11

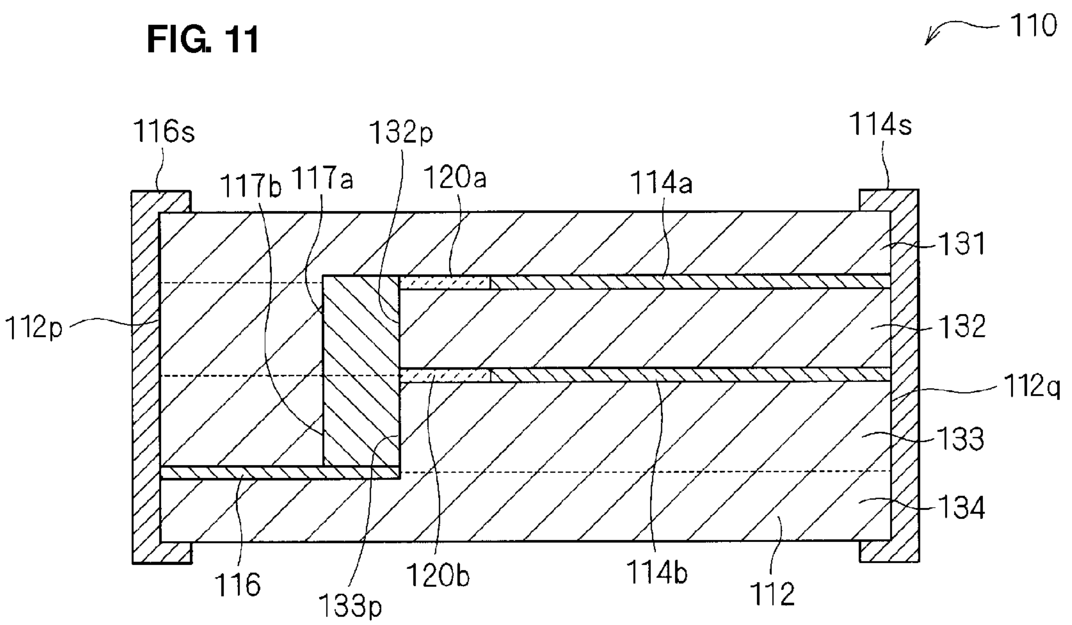
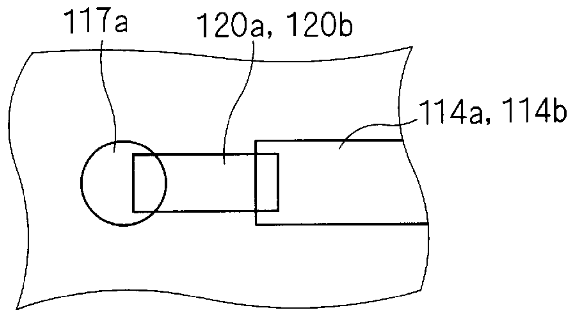

110
116s
132p
114s
117b
117a
120a
114a
131
112p
132
112q
133
134
116
133p
120b
114b
112

FIG. 12



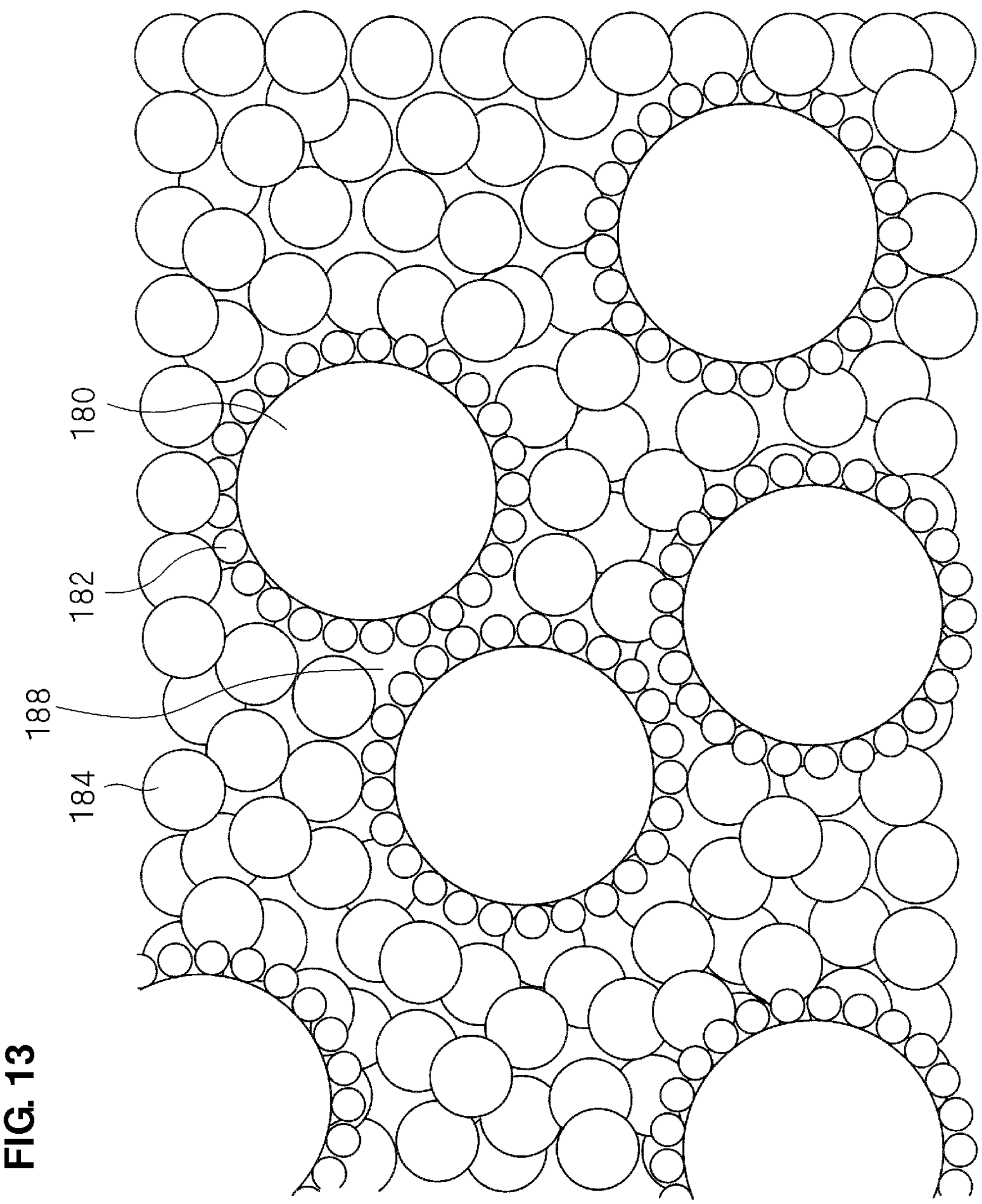


FIG. 13

FIG. 14

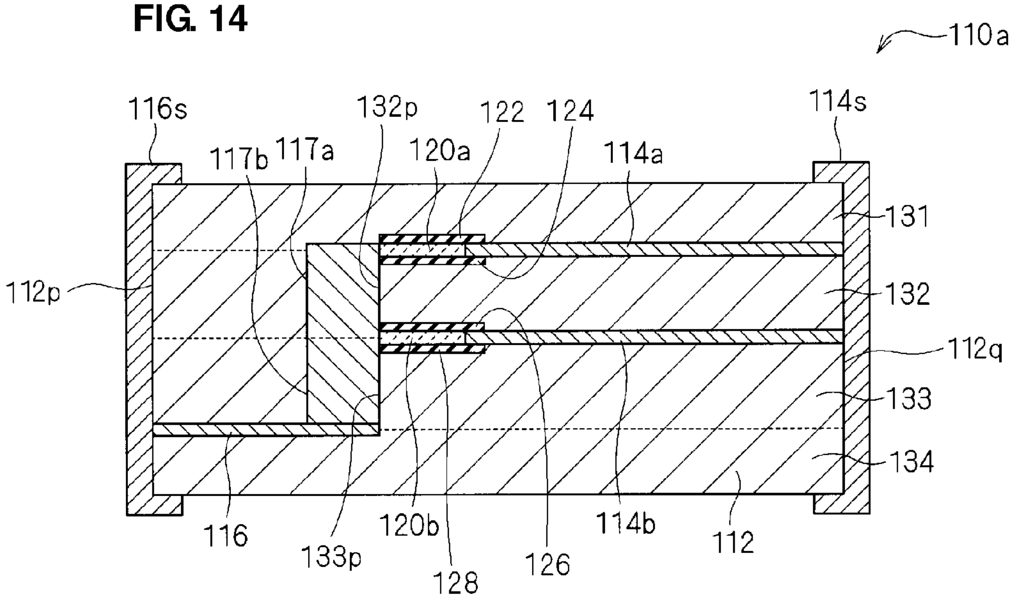


FIG. 15A

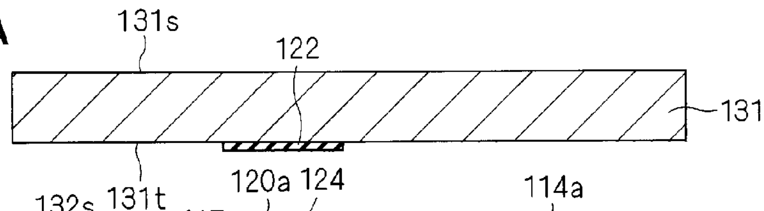


FIG. 15B

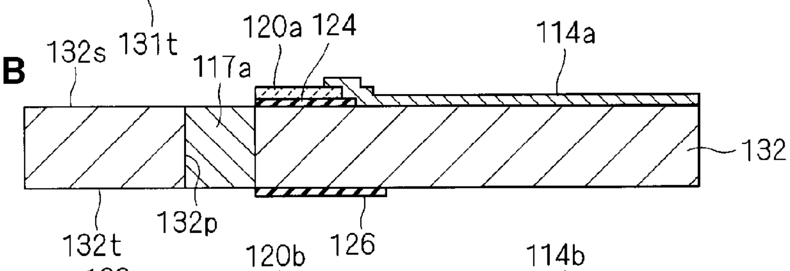


FIG. 15C

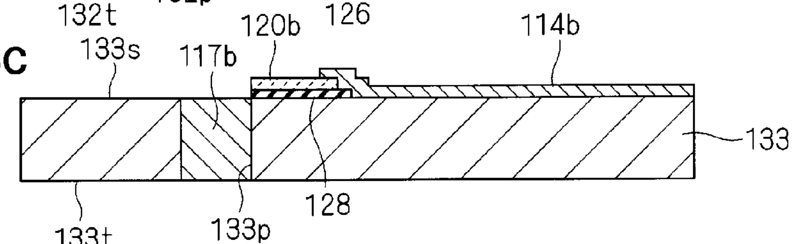


FIG. 15D

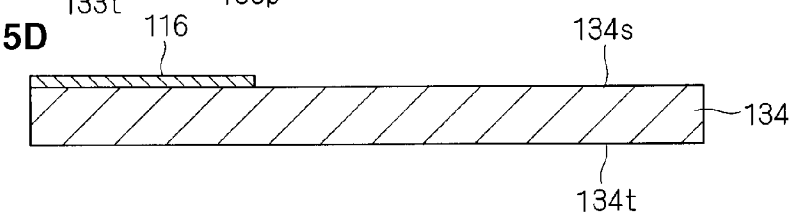


FIG. 16
PRIOR ART

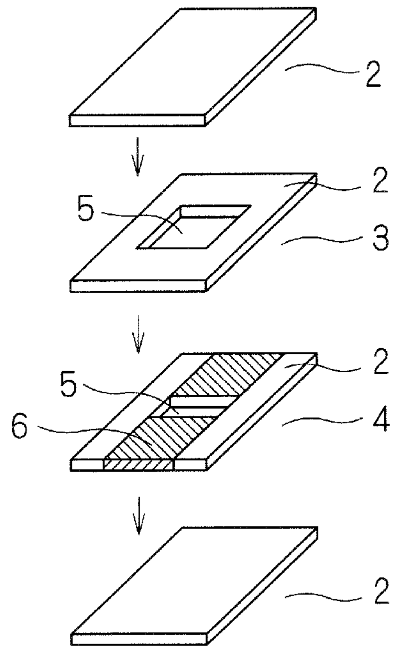
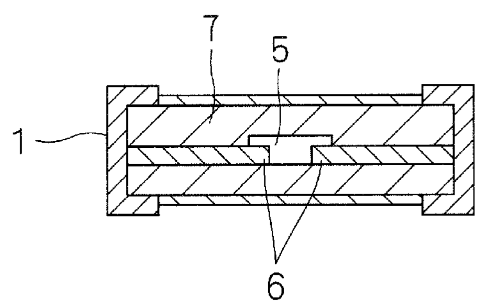


FIG. 17
PRIOR ART



ESD PROTECTION DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an ESD protection device, in particular, to an ESD protection device such as a single component having an ESD protection function only (ESD protection device) or a composite component (module) having an ESD protection function and another function.

2. Description of the Related Art

Electro-static discharge (ESD) is a phenomenon that, when a charged electrically conductive object (such as a human body) comes into contact with or comes sufficiently close to another electrically conductive object (such as an electronic device), a strong discharge is generated. ESD causes problems such as damage to and malfunction of electronic devices. To avoid such problems, an excessively high voltage generated at the time of discharge needs to be prevented from being applied to circuits of electronic devices. For such a purpose, ESD protection devices are used and they are also called surge absorbing devices or surge absorbers.

For example, such an ESD protection device is disposed between a signal path of a circuit and the ground. The ESD protection device has a structure in which a pair of discharge electrodes are opposed to each other at a distance from each other. Accordingly, the device has a high resistance and hence signals do not flow to the ground in the normal usage state. However, when an excessively high voltage is applied, for example, in the case of application of static electricity to a cellular phone through the antenna of the cellular phone, a discharge is generated between the discharge electrodes of the ESD protection device so that the static electricity can be made to flow to the ground. As a result, the voltage due to static electricity is not applied to the circuit disposed downstream of the ESD device to thereby protect the circuit.

For example, an ESD protection device illustrated in FIG. **16** (exploded perspective view) and FIG. **17** (sectional view) has the following configuration. In a ceramic multilayer substrate **7** in which insulating ceramic sheets **2** are laminated, a hollow portion **5** is formed; discharge electrodes **6** that are in electrical connection with outer electrodes **1** are disposed in the hollow portion **5** so as to oppose each other; and a discharge gas is contained in the hollow portion **5**. When a voltage that produces an electrical breakdown is applied between the discharge electrodes **6**, a discharge is generated between the discharge electrodes **6** in the hollow portion **5**. As a result of this discharge, the excessively high voltage is introduced to the ground. Thus, the circuit disposed downstream of the ESD protection device can be protected (See, for example, Japanese Unexamined Patent Application Publication No. 2001-43954).

In such an ESD protection device, the ESD responsivity needs to be adjusted by changing the area of the opposing regions of the discharge electrodes. However, this adjustment is limited by, for example, the product size. Accordingly, desired ESD responsivity is less likely to be achieved.

In addition, the ESD protection device has the following problems. When static electricity at a high voltage is successively applied to the device, the discharge electrodes begin to melt. Thus, a short circuit is caused between the discharge electrodes; or the distance between the discharge electrodes is increased and the discharge starting voltage is increased.

SUMMARY OF THE INVENTION

Under the circumstances, preferred embodiments of the present invention provide an ESD protection device in which

desired ESD responsivity can be easily achieved and the reliability of the ESD protection function can be enhanced.

An ESD protection device according to a preferred embodiment of the present invention includes a ceramic multilayer substrate in which a plurality of ceramic insulating layers are laminated; a first connecting conductor that has electrical conductivity and extends through main surfaces of at least one of the insulating layers; a mixture portion that extends along one of the main surfaces of the insulating layer including the first connecting conductor and is connected to the first connecting conductor, the mixture portion including a material dispersed therein, the material containing at least one selected from (i) a metal and a semiconductor, (ii) a metal and a ceramic, (iii) a metal, a semiconductor, and a ceramic, (iv) a semiconductor and a ceramic, (v) a semiconductor, (vi) a metal coated with an inorganic material, (vii) a metal coated with an inorganic material and a semiconductor, (viii) a metal coated with an inorganic material and a ceramic, and (ix) a metal coated with an inorganic material, a semiconductor, and a ceramic; and a second connecting conductor that has electrical conductivity, is separated from the first connecting conductor, is connected to the mixture portion, and extends along the main surface of the at least one insulating layer on which the mixture portion is provided.

In this case, when a voltage of a predetermined value or higher is applied between the first connecting conductor and the second connecting conductor, a discharge is generated in the mixture portion.

In the above-described configuration, at least one of the discharge electrodes disposed with the mixture portion therebetween, that is, the first connecting conductor defines an interlayer connecting conductor. As a result, heat generated at the time of the application of static electricity can be dissipated through the interlayer connecting conductor having a higher thermal conductivity than in-plane connecting conductors. Thus, a temperature increase due to repeated discharge can be significantly reduced and prevented and melting of the discharge electrodes can be significantly reduced and prevented. Thus, the reliability of the ESD protection function can be enhanced.

As with the second connecting conductor, the mixture portion can be formed by a thick-film printing process, for example, and hence can be easily formed. Since the mixture portion can be disposed at a desired position in the lamination direction with respect to the interlayer connecting conductor, the degree of freedom in design can be enhanced. Thus, desired ESD responsivity can be easily achieved.

In a preferred embodiment of the present invention, the second connecting conductor preferably extends along the main surface of the at least one insulating layer on which the mixture portion is provided and surrounds the outer periphery of the mixture portion, and is electrically connected to the outer periphery of the mixture portion; and the first connecting conductor is concentric with the mixture portion and extends through the main surfaces of the at least one insulating layer, and is electrically connected to the mixture portion so as to be separated from the outer periphery of the mixture portion.

In this case, since the entirety of the circular periphery of the mixture portion connected to the second connecting conductor is used, the discharge width is increased to facilitate discharging. By forming the mixture portion in the shape of a concentric circle, an ESD discharge portion having a greatly increased size can be formed in a limited area. Since the entirety of the circular periphery of the mixture portion connected to the second connecting conductor is used, the discharge width is increased to facilitate discharging. Thus, desired ESD responsivity can be easily achieved.

A hollow portion is preferably arranged in contact with the mixture portion and a main surface of the second connecting conductor.

In this case, by forming the hollow portion, a gaseous discharge can be generated and ESD characteristics can be further enhanced.

The first connecting conductor is preferably directly connected to the mixture portion.

In this case, the configuration can be simplified. The first connecting conductor may be disposed such that an end surface of the first connecting conductor is just in contact with the center of the mixture portion and the first connecting conductor does not extend through the mixture portion. Alternatively, an opening may be provided in the center of the mixture portion and the periphery of the opening may be connected to the outer periphery of the second connecting conductor.

In a preferred configuration, an opening is provided in a center of the mixture portion; a third connecting conductor is further provided that has electrical conductivity, extends along the main surface of the at least one insulating layer on which the mixture portion is located, and is connected to the periphery of the opening of the mixture portion; and the first connecting conductor is connected to the third connecting conductor.

In this case, while a sufficiently large discharge width is provided, the distance (discharge gap) between the first connecting conductor and the third connecting conductor that oppose each other via the mixture portion can be decreased.

In the mixture portion, a metal material and a semiconductor material are preferably dispersed.

In this case, the metal material and the semiconductor material are dispersed in the mixture portion in which a discharge is generated. Accordingly, electrons easily move and the discharge phenomenon occurs more efficiently. Thus, ESD responsivity can be enhanced.

In addition, fluctuations in the ESD responsivity due to variations in the distance between the discharge electrodes can be reduced. Thus, the adjustment and stabilization of ESD characteristics can be easily achieved.

In a preferred embodiment, the semiconductor material is silicon carbide or zinc oxide, for example.

In the mixture portion, a metal material coated with an insulating inorganic material is preferably dispersed.

In this case, since metal material particles in the mixture portion are coated with the inorganic material, the metal material particles are not in direct contact with each other. Accordingly, the probability of the occurrence of a short circuit due to the connection among the metal material particles is significantly decreased.

A sealing layer is preferably further provided between the insulating layer and the mixture portion and/or between the insulating layer and the hollow portion, so as to extend along the insulating layer.

In this case, permeation of a glass component in the ceramic multilayer substrate into the mixture portion can be significantly reduced and prevented.

A hollow is preferably formed so as to be in contact with the first connecting conductor, the mixture portion, and the second connecting conductor.

In this case, by forming the hollow, a gaseous discharge can be generated and ESD characteristics can be further enhanced.

In the mixture portion, a metal material and a semiconductor material are preferably dispersed.

In this case, the metal material and the semiconductor material are dispersed in the mixture portion in which a discharge is generated. Accordingly, electrons easily move and the discharge phenomenon occurs more efficiently. Thus, ESD responsivity can be enhanced.

In addition, fluctuations in the ESD responsivity due to variations in the distance between the discharge electrodes can be reduced. Thus, the adjustment and stabilization of ESD characteristics can be easily achieved.

In a preferred embodiment, the semiconductor material dispersed in the mixture portion is silicon carbide or zinc oxide.

In the mixture portion, a metal material coated with an insulating inorganic material is preferably dispersed.

In this case, since metal material particles in the mixture portion are coated with the inorganic material, the metal material particles are not in direct contact with each other. Accordingly, the probability of the occurrence of a short circuit due to the connection among the metal material particles is decreased.

A sealing layer is preferably further provided between the insulating layer and the mixture portion and/or between the insulating layer and the hollow, so as to extend along the insulating layer.

In this case, permeation of a glass component in the ceramic multilayer substrate into the mixture portion can be suppressed.

According to various preferred embodiments of the present invention, desired ESD responsivity can be easily achieved and the reliability of the ESD protection function can be enhanced.

The above and other elements, features, steps, characteristics and advantages of the present invention will become more apparent from the following detailed description of the preferred embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic view of an ESD protection device according to a first preferred embodiment of the present invention.

FIG. **2** is a sectional view of an ESD protection device according to the first preferred embodiment of the present invention.

FIG. **3** is a sectional view of a main portion of an ESD protection device according to the first preferred embodiment of the present invention.

FIG. **4** is a sectional view of an ESD protection device according to a first modification of the first preferred embodiment of the present invention.

FIGS. **5**A-**5**D include sectional views illustrating steps for producing an ESD protection device according to the first modification of the first preferred embodiment of the present invention.

FIG. **6** is a sectional view of a main portion of an ESD protection device according to a second modification of the first preferred embodiment of the present invention.

FIG. **7** is a sectional view of a main portion of an ESD protection device according to a third modification of the first preferred embodiment of the present invention.

FIGS. **8**A and **8**B include sectional views of a main portion of an ESD protection device according to a fourth modification of the first preferred embodiment of the present invention.

FIG. **9** schematically illustrates the structure of a mixture portion according to the first preferred embodiment of the present invention.

FIG. **10** is a sectional view of an ESD protection device according to a second preferred embodiment of the present invention.

FIG. **11** is a sectional view of an ESD protection device according to a third preferred embodiment of the present invention.

FIG. **12** is a sectional view of an ESD protection device according to a modification of the third preferred embodiment of the present invention.

FIG. **13** schematically illustrates the structure of a mixture portion according to the third preferred embodiment of the present invention.

FIG. **14** is a sectional view of an ESD protection device according to a fourth preferred embodiment of the present invention.

FIGS. **15**A-**15**D include sectional views illustrating steps for producing an ESD protection device according to the fourth preferred embodiment of the present invention.

FIG. **16** is an exploded perspective view of an ESD protection device according to an existing example.

FIG. **17** is a sectional view of an ESD protection device according to an existing example.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, preferred embodiments according to the present invention will be described with reference to FIGS. **1** to **15**.

First Preferred Embodiment

An ESD protection device **10** according to a first preferred embodiment will be described with reference to FIGS. **1** to **3** and **9**.

FIG. **1** is a schematic view illustrating the internal structure of the ESD protection device **10**. FIG. **2** is a sectional view of the ESD protection device **10**. FIG. **3** is a sectional view of a main portion taken along line A-A in FIG. **2**.

As illustrated in FIGS. **1** to **3**, the ESD protection device **10** includes a ceramic multilayer substrate **12** in which first to fourth insulating layers **41** to **44** composed of a ceramic material are laminated. The ceramic multilayer substrate **12** includes a mixture portion **20**, first to third in-plane connecting conductors **14**, **16**, and **17**, and first and second interlayer connecting conductors **15***a* and **15***x*.

The mixture portion **20** and the second and third in-plane connecting conductors **16** and **17** are disposed between the second and third insulating layers **42** and **43**, which are next to each other, so as to extend along opposing main surfaces of the second and third insulating layers **42** and **43**.

As illustrated in FIG. **3**, the mixture portion **20** preferably has an outer periphery **20***s* that is circular or substantially circular. The third in-plane connecting conductor **17** is surrounds the outer periphery **20***s* of the mixture portion **20** and is connected to the entirety of the outer periphery **20***s* of the mixture portion **20**. The third connecting conductor **17** is connected to the second in-plane connecting conductor **16**. The third in-plane connecting conductor **17** serves as a second connecting conductor.

As illustrated in FIG. **2**, in the second and third insulating layers **42** and **43**, first and second via holes (through holes) **42***p* and **43***p* extending through main surfaces of the second and third insulating layers **42** and **43** are concentric with the mixture portion **20**. In the first and second via holes **42***p* and **43***p*, the first and second interlayer connecting conductors **15***a* and **15***x* are provided.

In the interlayer connecting conductors **15***a* and **15***x*, opposing end surfaces thereof in a direction in which the insulating layers **41** to **44** are laminated (vertical direction in FIG. **2**) are joined together. Specifically, as illustrated in FIG. **3**, an opening **20***p* is formed in the center of the mixture portion **20**; and the interlayer connecting conductors **15***a* and **15***x* extend through the opening **20***p*. The outer periphery of the interlayer connecting conductors **15***a* and **15***x* is connected to the periphery of the opening **20***p* of the mixture portion **20**. The first interlayer connecting conductor **15***a* serves as a first connecting conductor.

As illustrated in FIG. **2**, the first in-plane connecting conductor **14** is located between the first and second insulating layers **41** and **42**, which are next to each other, so as to extend along opposing main surfaces of the first and second insulating layers **41** and **42**. The first interlayer connecting conductor **15***a* is connected to the first in-plane connecting conductor **14**.

The first and second in-plane connecting conductors **14** and **16** extend to the side surfaces of the ceramic multilayer substrate **12** and are respectively connected to first and second outer terminals **14***x* and **16***x*.

The first to third in-plane connecting conductors **14**, **16**, and **17**, the first and second interlayer connecting conductors **15***a* and **15***x*, and the first and second outer terminals **14***x* and **16***x* have electrical conductivity.

In the mixture portion **20**, a material is dispersed, the material containing at least one selected from (i) a metal and a semiconductor, (ii) a metal and a ceramic, (iii) a metal, a semiconductor, and a ceramic, (iv) a semiconductor and a ceramic, (v) a semiconductor, (vi) a metal coated with an inorganic material, (vii) a metal coated with an inorganic material and a semiconductor, (viii) a metal coated with an inorganic material and a ceramic, and (ix) a metal coated with an inorganic material, a semiconductor, and a ceramic. The mixture portion **20** has an insulating property on the whole.

For example, as illustrated in FIG. **9** schematically illustrating the structure of the mixture portion **20**, metal material particles **80** coated with inorganic material particles having an insulating property, semiconductor material particles **84**, and cavities **88** are dispersed in the mixture portion **20**. For example, the metal material particles **80** are Cu particles having a diameter of about 2 μm to about 3 μm; the inorganic material particles **82** are Al_2O_3 particles having a diameter of about 1 μm or less; and the semiconductor material particles **84** are composed of silicon carbide, zinc oxide, or the like.

The inorganic material and the semiconductor material may react during firing to exhibit different properties after the firing. The semiconductor material and a ceramic powder forming the ceramic multilayer substrate may also react during firing to exhibit different properties after the firing.

When the metal material is not coated with the inorganic material, metal material particles may be in contact with each other before firing and the connection among the metal material particles may result in a short circuit. In contrast, when the metal material is coated with the inorganic material, metal material particles are not in contact with each other before firing. In addition, even when the inorganic material exhibits different properties after the firing, the state where the metal material particles are separated from each other is maintained. Accordingly, coating of the metal material with the inorganic material significantly decreases the probability that the connection among the metal material particles is formed and a short circuit is caused.

Instead of the metal material coated with the inorganic material, the material for forming the mixture portion may be composed of a metal material and a semiconductor or a ceramic, or a combination of the foregoing. Alternatively, the material for forming the mixture portion may be composed of a semiconductor only without metal materials; a semiconductor and a ceramic only; or a metal material coated with an inorganic material only.

When a voltage of a predetermined value or higher is applied from the outer terminals **14**x and **16**x to the ESD protection device **10** illustrated in FIGS. **1** to **3**, a discharge is generated, through the mixture portion **20**, between the third in-plane connecting conductor **17** and the first and second interlayer connecting conductors **15**a and **15**x, the third in-plane connecting conductor **17** opposing the first and second interlayer connecting conductors **15**a and **15**x.

The discharge starting voltage can be set at a desired value by adjusting, for example, the peripheral lengths (that is, discharge widths) of portions over which the third connecting conductor **17** opposes the first and second interlayer connecting conductors **15**a and **15**x via the mixture portion **20**; the radial distances (that is, discharge gaps) between the third connecting conductor **17** and the first and second interlayer connecting conductors **15**a and **15**x, the third connecting conductor **17** opposing the first and second interlayer connecting conductors **15**a and **15**x via the mixture portion **20**; the thickness of the mixture portion **20**; or the amounts or types of materials contained in the mixture portion **20**.

By connecting the third in-plane connecting conductor **17** to the entirety of the circular outer periphery **20**s of the mixture portion **20** and by generating a discharge with the circular periphery, the discharge width is increased to facilitate discharging. By forming the mixture portion **20** in the shape of a circle concentric with the third connecting conductor **17** and the first and second interlayer connecting conductors **15**a and **15**x serving as discharge electrodes, an ESD discharge portion having a significantly increased size can be formed in a limited area.

As with the first to third in-plane connecting conductors **14**, **16**, and **17**, the mixture portion **20** can be formed by a thick-film printing process, for example. Accordingly, the mixture portion **20** can be easily formed and the thickness thereof can be easily adjusted. Since the mixture portion **20** can be provided along a main surface of a desired insulating layer in the ceramic multilayer substrate, the degree of freedom with which the position of the mixture portion **20** is designed is enhanced.

Since the mixture portion **20** contains not only a metal material but also a semiconductor material, even when the content of the metal material is low, desired ESD responsivity can be obtained. In addition, the occurrence of short circuits due to contact between metal material particles can be significantly reduced and prevented.

The material contained in the mixture portion **20** may include a portion or all of the materials forming the ceramic multilayer substrate **12**. When the mixture portion **20** contains the same material as the material of the ceramic multilayer substrate **12**, for example, the shrinking behavior of the mixture portion **20** during firing can be easily made to match that of the ceramic multilayer substrate **12**. Accordingly, the adhesion of the mixture portion **20** to the ceramic multilayer substrate **12** is enhanced and separation of the mixture portion **20** during firing becomes less likely to occur. In addition, the resistance to repeated ESD is also enhanced. The number of the types of materials used can also be decreased.

The metal material contained in the mixture portion **20** may be the same as or different from the material of the first to third in-plane connecting conductors **14**, **16**, and **17**. When the mixture portion **20** contains the same material as the first to third in-plane connecting conductors **14**, **16**, and **17**, for example, the shrinking behavior of the mixture portion **20** can be easily made to match that of the first to third in-plane connecting conductors **14**, **16**, and **17**, and the number of the types of materials used can be decreased.

A hollow portion may be formed so as to be in contact with the mixture portion **20** and a main surface of the third connecting conductor **17**. In this case, by forming the hollow portion, a gaseous discharge can be generated and ESD characteristics can be further enhanced.

Hereinafter, a non-limiting example of a method for producing the ESD protection device **10** will be described.

Ceramic green sheets that have a thickness of 50 μm and are to serve as the first to fourth insulating layers **41** to **44** are first prepared.

A ceramic material that serves as the material of the ceramic multilayer substrate **12** has a composition mainly containing Ba, Al, and Si. Raw materials are prepared and mixed so as to achieve a predetermined composition and calcined at 800° C. to 1000° C. The resultant calcined powder is pulverized with a zirconia-ball mill for 12 hours to provide a ceramic powder. This ceramic powder is mixed with an organic solvent such as toluene or EKINEN, and further mixed with a binder and a plasticizer to provide a slurry. The thus-obtained slurry is formed by the doctor blade technique to provide ceramic green sheets that have a thickness of 50 μm and are to serve as the first to fourth insulating layers **41** to **44**.

An electrode paste for forming the first to third in-plane connecting conductors **14**, **16**, and **17** and the first and second interlayer connecting conductors **15**a and **15**x is prepared. A solvent is added to 80 wt % of a Cu powder having an average particle size of about 1.5 μm and a binder resin containing ethyl cellulose or the like. The resultant substance is stirred and mixed with a roll to provide the electrode paste.

A mixture paste for forming the mixture portion **20** is also prepared. The mixture paste is obtained by preparing an Al_2O_3-coated Cu powder having an average particle size of about 2 μm and, as a semiconductor material, silicon carbide (SiC) having an average particle size of 1 μm to achieve predetermined proportions; by adding a binder resin and a solvent to the resultant substance; and by stirring and mixing the resultant substance with a roll. The mixture paste contains 20 wt % of the binder resin and the solvent, and the remainder, 80 wt % of the Al_2O_3-coated Cu powder and silicon carbide.

In the ceramic green sheets that are to serve as the second and third insulating layers **42** and **43**, the via holes **42**p and **43**p are formed with laser or a mold. The via holes **42**p and **43**p are then filled with the electrode paste by screen printing to form portions that are to serve as the first and second interlayer connecting conductors **15**a and **15**x.

The mixture paste is then applied to the ceramic green sheet that is to serve as the third insulating layer **43** by screen printing to form a portion that is to serve as the mixture portion **20**. The portion that is to serve as the mixture portion **20** may be formed on the ceramic green sheet that is to serve as the second insulating layer **42**.

The electrode paste is then applied to the ceramic green sheets that are to serve as the second and third insulating layers **42** and **43** by screen printing to form portions that are to serve as the first to third in-plane connecting conductors **14**, **16**, and **17**. The portion that is to serve as the first in-plane connecting conductor **14** may be formed on the ceramic green sheet that is to serve as the first insulating layer **41**. The portions that are to serve as the second and third in-plane connecting conductors **16** and **17** may be formed on the ceramic green sheet that is to serve as the second insulating layer **42**.

After the portions that are to serve as the first to third in-plane connecting conductors **14**, **16**, and **17** are formed, the portion that is to serve as the mixture portion **20** may be formed.

When a hollow portion is formed so as to be in contact with the mixture portion **20** and a main surface of the third connecting conductor **17**, a resin paste that can be eliminated (such as an acrylic paste or a carbon paste) is applied by screen printing onto the previously formed portions that are to serve as the mixture portion **20** and the in-plane connecting conductor **17** such that one of the portions that are to serve as the first and second interlayer connecting conductors **15***a* and **15***x* is exposed.

As with the standard ceramic multilayer substrates, the ceramic green sheets are laminated and press-bonded.

As with chip-type electronic components such as LC filters, the resultant laminated body is cut with a microcutter into chips. After that, the electrode paste is applied to the end surfaces of the chips to form the outer terminals.

As with the standard ceramic multilayer substrates, the chips are then fired in N_2 atmosphere. In the case of using an electrode material that is not oxidized (such as Ag), the firing may be performed in the air atmosphere. The firing causes elimination of the organic solvent in the ceramic green sheets and the binder resin and the solvent in the mixture paste. As a result, the mixture portion **20** in which Al_2O_3-coated Cu, SiC, and cavities are dispersed is formed.

As with chip-type electronic components such as LC filters, the outer terminals are electrolytically plated with Ni—Sn.

Thus, the ESD protection device **10** having a section illustrated in FIG. **2** has been completed.

The semiconductor material is not particularly limited to the above-described material. Examples of the semiconductor material include semiconductors of metals such as silicon and germanium; carbides such as silicon carbide, titanium carbide, zirconium carbide, molybdenum carbide, and tungsten carbide; nitrides such as titanium nitride, zirconium nitride, chromium nitride, vanadium nitride, and tantalum nitride; silicides such as titanium silicide, zirconium silicide, tungsten silicide, molybdenum silicide, and chromium silicide; borides such as titanium boride, zirconium boride, chromium boride, lanthanum boride, molybdenum boride, and tungsten boride; and oxides such as zinc oxide and strontium titanate. In particular, silicon carbide and zinc oxide are preferred because they are relatively inexpensive and products having various particle sizes are commercially available. Such semiconductor materials may be properly used alone or in combination of two or more thereof. Such a semiconductor material may be properly used in the form of a mixture with a resistive material such as alumina or a BAS material.

The metal material is not particularly limited to the above-described material. Examples of the metal material include Cu, Ag, Pd, Pt, Al, Ni, W, and Mo, alloys of the foregoing, and combinations of the foregoing.

In the first preferred embodiment, the case in which the ESD protection device **10** is a single component having an ESD protection function only (ESD protection device) is described as an example. Alternatively, the ESD protection device may be, for example, a composite component (module) having the ESD protection function and another function. When the ESD protection device is, for example, such a composite component (module), it at least includes the mixture portion **20** and the third in-plane connecting conductor **17** and the first interlayer connecting conductor **15***a* that are connected to the mixture portion **20**.

First Modification of First Preferred Embodiment

An ESD protection device **10***a* according to a first modification of the first preferred embodiment of the present invention will be described with reference to FIGS. **4** and **5**.

FIG. **4** is a sectional view of the ESD protection device **10***a* according to the first modification. As illustrated in FIG. **4**, the ESD protection device **10***a* according to the first modification has substantially the same configuration as the ESD protection device **10** according to the first preferred embodiment. Hereinafter, like reference signs in the first preferred embodiment will be used to denote like elements and differences from the first preferred embodiment will be mainly described.

As illustrated in FIG. **4**, the ESD protection device **10***a* according to the first modification includes, in addition to the configuration of the first preferred embodiment, sealing layers **22** and **24** disposed between the mixture portion **20** and the second and third insulating layers **42** and **43** of a ceramic multilayer substrate **12***a*. The sealing layers **22** and **24** significantly reduce and prevent permeation of a glass component in the ceramic multilayer substrate **12***a* into the mixture portion **20**. The sealing layers **22** and **24** have an insulating property.

As illustrated in sectional views in FIG. **5**A to **5**D, the sealing layers **22** and **24** can be produced by forming, laminating, press-bonding, and firing the ceramic green sheets that are to serve as the first to fourth insulating layers **41** to **44**.

Specifically, as illustrated in FIGS. **5**A and **5**D, the ceramic green sheets that are to serve as the first and fourth insulating layers **41** and **44** are prepared.

As illustrated in FIGS. **5**B and **5**C, in the ceramic green sheets that are to serve as the second and third insulating layers **42** and **43**, the via holes **42***p* and **43***p* are formed. The via holes **42***p* and **43***p* are filled with the electrode paste to form portions that are to serve as the first and second interlayer connecting conductors **15***a* and **15***x*.

A paste for forming the sealing layers is then applied by screen printing onto opposing surfaces **42***t* and **43***s* of the ceramic green sheets that are to serve as the second and third insulating layers **42** and **43**. Thus, the sealing layers **22** and **24** having openings **22***p* and **24***p* are formed. The sealing layers **22** and **24** are then dried. The sealing layers **22** and **24** are formed such that portions that are to serve as the first and second interlayer connecting conductors **15***a* and **15***x* are exposed through the openings **22***p* and **24***p* of the sealing layers **22** and **24**.

The mixture portion **20** having the opening **20***p* is then formed from a mixture paste on the sealing layer **24** on the ceramic green sheet that is to serve as the third insulating layer **43**. The mixture portion **20** is formed such that the portion that is to serve as the second interlayer connecting conductor **15***x* is exposed through the opening **20***p* of the mixture portion **20**. In addition, the portions that are to serve as the second and third in-plane connecting conductors **16** and **17** are formed from an electrode paste on the ceramic green sheet that is to serve as the third insulating layer **43**. Alternatively, after the portions that are to serve as the second and third in-plane connecting conductors **16** and **17** are formed on the ceramic green sheet that is to serve as the third insulating layer **43**, the portion that is to serve as the mixture portion **20** may be formed.

The sealing layer **22** may be formed on the ceramic green sheet that is to serve as the third insulating layer **43**. Specifically, on the ceramic green sheet that is to serve as the third insulating layer **43**, after the sealing layer **24**, the portion that is to serve as the mixture portion **20**, and the portions that are to serve as the second and third in-plane connecting conductors **16** and **17** are formed, the sealing layer **22** may be formed.

On the contrary, on the ceramic green sheet that is to serve as the second insulating layer **42**, after the sealing layer **22**, the portions that are to serve as the second and third in-plane connecting conductors **16** and **17**, and the portion that is to serve as the mixture portion **20** are formed, the sealing layer **24** may be formed.

The paste for forming the sealing layers **22** and **24** is prepared in the same manner as in the electrode paste. For example, a solvent is added to 80 wt % of an Al_2O_3 powder having an average particle size of about 1 μm and a binder resin containing ethyl cellulose or the like; the resultant substance is stirred and mixed with a roll to provide the paste (alumina paste) for forming the sealing layers. The solid component of the paste for forming the sealing layers is selected from materials having a higher sintering temperature than the material of the ceramic multilayer substrate, such as alumina, zirconia, magnesia, mullite, and quartz.

When a hollow portion is formed so as to be in contact with the mixture portion **20** and the third in-plane connecting conductor **17**, a resin paste that can be eliminated (such as an acrylic paste or a carbon paste) is formed on the third in-plane connecting conductor **17** and the mixture portion **20** that are formed on the ceramic green sheet that is to serve as the third insulating layer **43**, such that the portion that is to serve as the second interlayer connecting conductor **15***x* is exposed. By forming the hollow portion, a gaseous discharge can be generated and ESD characteristics can be further enhanced.

Second Modification of First Preferred Embodiment

An ESD protection device **10***b* according to a second modification of the first preferred embodiment of the present invention will be described with reference to FIG. **6**.

FIG. **6** is a sectional view of a main portion of the ESD protection device **10***b* according to the second modification. As illustrated in FIG. **6**, as in the first preferred embodiment, the ESD protection device **10***b* according to the second modification includes, in a ceramic multilayer substrate **12***b*, the first to third in-plane connecting conductors **14**, **16**, and **17**, an interlayer connecting conductor **15***b* connected to the first in-plane connecting conductor **14**, and a mixture portion **20***b*. The third in-plane connecting conductor **17** is connected to the circular outer periphery **20***s* of the mixture portion **20***b*.

Unlike the first preferred embodiment, the opening is not formed in the center of the mixture portion **20***b* and the interlayer connecting conductor **15***b* does not extend through the mixture portion **20***b*. An end surface **15***s* of the interlayer connecting conductor **15***b* in the lamination direction is in contact with an upper surface **20***t* of the mixture portion **20***b* so as to be connected to the central portion of the mixture portion **20***b*.

A hollow portion may be formed on the upper surface **20***t* side of the mixture portion **20***b* so as to be in contact with the mixture portion **20***b*, a main surface of the third in-plane connecting conductor **17**, and the side surface of the interlayer connecting conductor **15***b*. By forming the hollow portion, a gaseous discharge can be generated and ESD characteristics can be further enhanced.

Third Modification of First Preferred Embodiment

An ESD protection device **10***c* according to a third modification of the first preferred embodiment of the present invention will be described with reference to FIG. **7**.

FIG. **7** is a sectional view of a main portion of the ESD protection device **10***c* according to the third modification. As illustrated in FIG. **7**, the ESD protection device **10***c* according to the third modification has substantially the same configuration as in the first preferred embodiment.

Unlike the first preferred embodiment, in the ESD protection device **10***c* according to the third modification, the mixture portion **20**, the third in-plane connecting conductor **17** connected to the outer periphery **20***s* of the mixture portion **20**, and the second in-plane connecting conductor **16** connected to the third in-plane connecting conductor **17** are formed on a surface **12***s* of a ceramic multilayer substrate **12***c*. The outer periphery of an end (in the lamination direction) of the interlayer connecting conductor **15***c* formed in a via hole **51***p* in the outermost insulating layer **51** is connected to the periphery of the opening **20***p* in the central portion of the mixture portion **20**. The other end (in the lamination direction) of the interlayer connecting conductor **15***c* is connected to the first in-plane connecting conductor **14** formed between the insulating layers **51** and **52**, which are next to each other.

When a voltage higher than a predetermined value is applied between the interlayer connecting conductor **15***c* and the third in-plane connecting conductor **17** through the first and second in-plane connecting conductors **14** and **16**, a discharge is generated, through the mixture portion **20**, between the interlayer connecting conductor **15***c* and the third in-plane connecting conductor **17**.

Since the mixture portion **20** and the second and third in-plane connecting conductors **16** and **17** are formed on the surface **12***s* of the ceramic multilayer substrate **12***c*, they are preferably covered with a cover layer **13** having an insulating property. Instead of the cover layer **13**, cover members that are separated from each other and cover the mixture portion **20** and the second and third in-plane connecting conductors **16** and **17** may be formed on the ceramic multilayer substrate **12***c*.

In FIG. **7**, a hollow portion may be formed so as to be in contact with the mixture portion **20** and the main surface **12***s* (on the insulating layer **51** side) or a main surface (on the cover layer **13** side) of the third in-plane connecting conductor **17**. By forming the hollow portion, a gaseous discharge can be generated and ESD characteristics can be further enhanced.

Fourth Modification of First Preferred Embodiment

An ESD protection device **10***d* according to a fourth modification of the first preferred embodiment of the present invention will be described with reference to FIGS. **8**A and **8**B.

FIG. **8**A is a sectional view of a main portion of the ESD protection device **10***d* according to the fourth modification. FIG. **8**B is a sectional view taken along line B-B in FIG. **8**A. As illustrated in FIGS. **8**A and **8**B, as in the first preferred embodiment, the ESD protection device **10***d* according to the fourth modification includes, between neighboring insulating layers in a ceramic multilayer substrate **12***d*, a mixture portion **20***d* having an outer periphery **20***s* that is circular, the third in-plane connecting conductor **17** connected to the outer periphery **20***s* of the mixture portion **20***d*, and the second in-plane connecting conductor **16** connected to the third in-plane connecting conductor **17**.

Unlike the first preferred embodiment, in the ESD protection device **10***d* according to the fourth modification, a fourth in-plane connecting conductor **18** is formed in an opening **20***q* formed in a central portion of the mixture portion **20***d*. The outer periphery of the fourth in-plane connecting conductor **18** is connected to the periphery of the opening **20***q* of the mixture portion **20***d*. An upper surface **18***s* of the fourth in-plane connecting conductor **18** is connected to an end surface **15***t* (in the lamination direction) of an interlayer connecting conductor **15***d*. The other end (in the lamination direction) of the interlayer connecting conductor **15***d* is connected to the first in-plane connecting conductor **14**. The interlayer connecting conductor **15***d* serves as a first connecting conductor. The fourth in-plane connecting conductor **18** serves as a third connecting conductor.

When a voltage higher than a predetermined value is applied between the third and fourth in-plane connecting conductors **17** and **18** through the first and second in-plane connecting conductors **14** and **16**, a discharge is generated, through the mixture portion **20***d*, between the third and fourth in-plane connecting conductors **17** and **18**.

In the ESD protection device **10***d*, while sufficiently large peripheral lengths (discharge widths) of portions over which the third and fourth in-plane connecting conductors **17** and **18** oppose each other via the mixture portion **20***d* are maintained, the radial distance (discharge gap) between the third and fourth in-plane connecting conductors **17** and **18** can be decreased.

In this case, a hollow portion may be formed so as to be in contact with the mixture portion **20***d* and a main surface of the third and fourth in-plane connecting conductors **17** and **18**. By forming the hollow portion, a gaseous discharge can be generated and ESD characteristics can be further enhanced.

Second Preferred Embodiment

An ESD protection device **110***x* according to a second preferred embodiment of the present invention will be described with reference to FIG. **10**.

FIG. **10** is a sectional view of the ESD protection device **110***x*. As illustrated in FIG. **10**, the ESD protection device **110***x* includes a ceramic multilayer substrate **112** in which first to fourth insulating layers **131** to **134** composed of a ceramic material are laminated. The ceramic multilayer substrate **112** includes a mixture portion **120***x*, first and second in-plane connecting conductors **114***x* and **116***x*, and first and second interlayer connecting conductors **117***a* and **117***b*.

In the second and third insulating layers **132** and **133**, via holes (through holes) **132***p* and **133***p* extending through the upper and lower main surfaces of the second and third insulating layers **132** and **133** are formed. In the via holes **132***p* and **133***p*, the first and second interlayer connecting conductors **117***a* and **117***b* are respectively formed. In the first and second interlayer connecting conductors **117***a* and **117***b*, opposing end surfaces thereof are joined together.

The mixture portion **120***x* is arranged along the upper main surface of the second insulating layer **132** including the first interlayer connecting conductor **117***a* and is connected to the first interlayer connecting conductor **117***a*. The first interlayer connecting conductor **117***a* serves as a first connecting conductor.

The first in-plane connecting conductor **114***x* is arranged along the upper main surface of the second insulating layer **132** including the first interlayer connecting conductor **117***a*. The first in-plane connecting conductor **114***x* is connected to the mixture portion **120***x*. The first in-plane connecting conductor **114***x* serves as a second connecting conductor. The first in-plane connecting conductor **114***x* is arranged so as to extend to a side surface **112***q* of the ceramic multilayer substrate **112**.

Instead of the first in-plane connecting conductor **114***x*, the second connecting conductor connected to the mixture portion **120***x* may be an interlayer connecting conductor arranged so as to extend through the main surfaces of one of the first and second insulating layers **131** and **132** (not shown). As in FIG. **12** described below, the end portions of the mixture portion **120***x* may be connected to the first interlayer connecting conductor **117***a* and the first in-plane connecting conductor **114***x* so as to overlap an end surface of the first interlayer connecting conductor **117***a* and an end portion of the first in-plane connecting conductor **114***x*.

The second in-plane connecting conductor **116***x* is disposed between the third and fourth insulating layers **133** and **134** so as to extend along opposing main surfaces of the third and fourth insulating layers **133** and **134**. The second in-plane connecting conductor **116***x* is connected to the second interlayer connecting conductor **117***b*. The second in-plane connecting conductor **116***x* is arranged so as to extend to another side surface **112***p* of the ceramic multilayer substrate **112**.

Outer terminals **116***s* and **114***s* are respectively disposed on the side surfaces **112***p* and **112***q* of the ceramic multilayer substrate **112**. One of the outer terminals, **116***s*, is connected to the second in-plane connecting conductor **116***x*. The other one of the outer terminals, **114***s*, is connected to the first in-plane connecting conductor **114***x*.

The first and second in-plane connecting conductors **114***x* and **116***x*, the first and second interlayer connecting conductors **117***a* and **117***b*, and the first and second outer terminals **114***s* and **116***s* have electrical conductivity.

In the mixture portion **120***x*, a material is dispersed, the material containing at least one selected from (i) a metal and a semiconductor, (ii) a metal and a ceramic, (iii) a metal, a semiconductor, and a ceramic, (iv) a semiconductor and a ceramic, (v) a semiconductor, (vi) a metal coated with an inorganic material, (vii) a metal coated with an inorganic material and a semiconductor, (viii) a metal coated with an inorganic material and a ceramic, and (ix) a metal coated with an inorganic material, a semiconductor, and a ceramic. The mixture portion **120***x* has an insulating property on the whole.

The ESD protection device **110***x* includes, as an interlayer connecting conductor, at least one of the discharge electrodes **114***x* and **117***a* that are disposed with the mixture portion **120***x* therebetween, that is, **117***a*. As a result, heat generated at the time of the application of static electricity can be dissipated through the interlayer connecting conductor having a higher thermal conductivity than in-plane connecting conductors. Thus, a temperature increase due to repeated discharge can be significantly reduced and prevented and melting of the discharge electrodes can be significantly reduced and prevented. In this case, by connecting the outer terminal **116***s*, which is close to the interlayer connecting conductor **117***a*, to the ground, a heat dissipation property can be enhanced. In addition, since the mixture portion can be disposed at a desired position in the lamination direction with respect to the interlayer connecting conductor, the degree of freedom in design can be enhanced.

Third Preferred Embodiment

An ESD protection device **110** according to a third preferred embodiment will be described with reference to FIGS. **11** to **13**.

FIG. **11** is a sectional view of the ESD protection device **110**. As illustrated in FIG. **11**, the ESD protection device **110** includes a ceramic multilayer substrate **112** in which first to fourth insulating layers **131** to **134** composed of a ceramic material are laminated. The ceramic multilayer substrate **112** includes mixture portions **120***a* and **120***b*, first to third in-plane connecting conductors **114***a*, **114***b*, and **116**, and first and second interlayer connecting conductors **117***a* and **117***b*.

In the second and third insulating layers **132** and **133**, via holes (through holes) **132***p* and **133***p* extending through the upper and lower main surfaces of the second and third insulating layers **132** and **133** are formed. In the via holes **132***p* and **133***p*, the first and second interlayer connecting conductors **117***a* and **117***b* are respectively provided. In the first and second interlayer connecting conductors **117***a* and **117***b*, opposing end surfaces thereof are joined together.

The first and second mixture portions **120***a* and **120***b* are respectively arranged along the upper and lower main surfaces of the second insulating layer **132** including the first interlayer connecting conductor **117***a* and are connected to the first interlayer connecting conductor **117***a*. The first interlayer connecting conductor **117***a* serves as a first connecting conductor.

The first and second in-plane connecting conductors **114***a* and **114***b* are respectively arranged along the upper and lower main surfaces of the second insulating layer **132** including the first interlayer connecting conductor **117***a*. The first and second in-plane connecting conductors **114***a* and **114***b* are respectively connected to the first and second mixture portions **120***a* and **120***b*. The first and second in-plane connecting conductors **114***a* and **114***b* serve as a second connecting conductor. The first and second in-plane connecting conductors **114***a* and **114***b* are arranged to extend to a side surface **112***q* of the ceramic multilayer substrate **112**.

Instead of the first in-plane connecting conductor **114***a*, the second connecting conductor connected to the first mixture portion **120***a* may be an interlayer connecting conductor arranged so as to extend through the main surfaces of one of the first and second insulating layers **131** and **132** (not shown). Instead of the second in-plane connecting conductor **114***b*, the second connecting conductor connected to the second mixture portion **120***b* may be an interlayer connecting conductor arranged so as to extend through the main surfaces of one of the second and third insulating layers **132** and **133**.

The third in-plane connecting conductor **116** is provided between the third and fourth insulating layers **133** and **134** so as to extend along opposing main surfaces of the third and fourth insulating layers **133** and **134**. The third in-plane connecting conductor **116** is connected to the second interlayer connecting conductor **117***b*. The third in-plane connecting conductor **116** is arranged so as to extend to another side surface **112***p* of the ceramic multilayer substrate **112**.

Outer terminals **114***s* and **116***s* are respectively provided on the side surfaces **112***q* and **112***p* of the ceramic multilayer substrate **112**. One of the outer terminals, **116***s*, is connected to the third in-plane connecting conductor **116**. The other one of the outer terminals, **114***s*, is connected to the first and second in-plane connecting conductors **114***a* and **114***b*.

FIG. **11** illustrates, as an example, the case where both ends of the first and second mixture portions **120***a* and **120***b* are connected to the first interlayer connecting conductor **117***a* and the first and second in-plane connecting conductors **114***a* and **114***b* so as to be in contact with the outer periphery of the first interlayer connecting conductor **117***a* and ends of the first and second in-plane connecting conductors **114***a* and **114***b*. Alternatively, as illustrated in a perspective view of FIG. **12**, the end portions of the first and second mixture portions **120***a* and **120***b* may be connected to the first interlayer connecting conductor **117***a* and the first and second in-plane connecting conductors **114***a* and **114***b* so as to overlap an end surface of the first interlayer connecting conductor **117***a* and end portions of the first and second in-plane connecting conductors **114***a* and **114***b*.

The first to third in-plane connecting conductors **114***a*, **114***b*, and **116**, the first and second interlayer connecting conductors **117***a* and **117***b*, and the first and second outer terminals **114***s* and **116***s* have electrical conductivity.

In the mixture portions **120***a* and **120***b*, a material is dispersed, the material containing at least one selected from (i) a metal and a semiconductor, (ii) a metal and a ceramic, (iii) a metal, a semiconductor, and a ceramic, (iv) a semiconductor and a ceramic, (v) a semiconductor, (vi) a metal coated with an inorganic material, (vii) a metal coated with an inorganic material and a semiconductor, (viii) a metal coated with an inorganic material and a ceramic, and (ix) a metal coated with an inorganic material, a semiconductor, and a ceramic. The mixture portions **120***a* and **120***b* have an insulating property on the whole.

For example, as illustrated in FIG. **13** schematically illustrating the structure of the mixture portions **120***a* and **120***b*, metal material particles **180** coated with inorganic material particles **182** having an insulating property, semiconductor material particles **184**, and cavities **188** are dispersed in the mixture portions **120***a* and **120***b*. For example, the metal material particles **180** are Cu particles having a diameter of about 2 μm to about 3 μm; the inorganic material particles **182** are Al_2O_3 particles having a diameter of about 1 μm or less; and the semiconductor material particles **184** are composed of silicon carbide, zinc oxide, or the like.

The inorganic material and the semiconductor material may react during firing to exhibit different properties after the firing. The semiconductor material and a ceramic powder of the ceramic multilayer substrate may also react during firing to exhibit different properties after the firing.

When the metal material is not coated with the inorganic material, metal material particles may be in contact with each other before firing and connection among the metal material particles may result in a short circuit. In contrast, when the metal material is coated with the inorganic material, metal material particles are not in contact with each other before firing. In addition, even when the inorganic material exhibits different properties after the firing, the state where the metal material particles are separated from each other is maintained. Accordingly, coating of the metal material with the inorganic material significantly decreases the probability that the connection among the metal material particles is formed and a short circuit is caused.

Instead of the metal material coated with the inorganic material, the material for forming the mixture portions may be composed of a metal material and a semiconductor or a ceramic, or a combination of the foregoing. Alternatively, the material for forming the mixture portions may be composed of a semiconductor only without metal materials; a semiconductor and a ceramic only; or a metal material coated with an inorganic material only.

When a voltage of a predetermined value or higher is applied from the outer terminals **114***s* and **116***s* to the ESD protection device **110** illustrated in FIG. **11**, a discharge is generated, through the mixture portions **120***a* and **120***b*, between the interlayer connecting conductor **117***a* and the first and second in-plane connecting conductors **114***a* and **114***b*.

The discharge starting voltage can be set at a desired value by adjusting, for example, the lengths (that is, discharge widths) of portions over which the first interlayer connecting conductor **117***a* opposes the first and second in-plane connecting conductors **114***a* and **114***b* via the first and second mixture portions **120***a* and **120***b*; the distances (that is, discharge gaps) between the interlayer connecting conductor **117***a* and the first and second in-plane connecting conductors **114***a* and **114***b*, the interlayer connecting conductor **117***a* opposing the first and second in-plane connecting conductors **114***a* and **114***b* via the mixture portions **120***a* and **120***b*; the thickness of the mixture portions **120***a* and **120***b*; or the amounts or types of materials contained in the mixture portions **120***a* and **120***b*.

The first and second mixture portions **120***a* and **120***b* are connected in parallel between the first and second in-plane connecting conductors **114**a and **114**b and the first interlayer connecting conductor **117**a. Accordingly, even when one of the first and second mixture portions **120**a and **120**b fails, the other one works. Thus, the reliability of the ESD protection function can be enhanced.

A hollow may be formed so as to be in contact with the mixture portions **120**a and **120**b, a main surface of the first in-plane connecting conductor **114**a, a main surface of the second in-plane connecting conductor **114**b, and the outer periphery or an end surface of the first interlayer connecting conductor **117**a. By forming the hollows, a gaseous discharge can be generated and ESD characteristics can be further enhanced.

As with the in-plane connecting conductors **114**a, **114**b, and **116**, the first and second mixture portions **120**a and **120**b can be formed by a thick-film printing process, for example. Accordingly, the first and second mixture portions **120**a and **120**b can be easily formed and the thickness thereof can be easily adjusted. Since the first and second mixture portions **120**a and **120**b can be formed along main surfaces of desired insulating layers in the ceramic multilayer substrate, the degree of freedom with which the positions of the mixture portions **120**a and **120**b are designed is enhanced.

Since the first and second mixture portions **120**a and **120**b contain not only a metal material but also a semiconductor material, even when the content of the metal material is low, desired ESD responsivity can be obtained. In addition, the occurrence of short circuits due to contact between metal material particles can be significantly reduced and prevented.

The material contained in the first and second mixture portions **120**a and **120**b may include a portion or all of the materials forming the ceramic multilayer substrate **112**. When the first and second mixture portions **120**a and **120**b contain the same material as the ceramic multilayer substrate **112**, for example, the shrinking behavior of the first and second mixture portions **120**a and **120**b during firing can be easily made to match that of the ceramic multilayer substrate **112**. Accordingly, the adhesion of the first and second mixture portions **120**a and **120**b to the ceramic multilayer substrate **112** is enhanced and separation of the first and second mixture portions **120**a and **120**b during firing becomes less likely to occur. In addition, the resistance to repeated ESD is also enhanced. The number of the types of materials used can also be decreased.

The metal material contained in the first and second mixture portions **120**a and **120**b may be the same as or different from the material of the first to third in-plane connecting conductors **114**a, **114**b, and **116**. When the first and second mixture portions **120**a and **120**b contain the same material as the first to third in-plane connecting conductors **114**a, **114**b, and **116**, for example, the shrinking behavior of the first and second mixture portions **120**a and **120**b can be easily made to match that of the first to third in-plane connecting conductors **114**a, **114**b, and **116**, and the number of the types of materials used can be decreased.

Hereinafter, a non-limiting example of a method for producing the ESD protection device **110** will be described.

Ceramic green sheets that are to serve as the first to fourth insulating layers **131** to **134** of the ceramic multilayer substrate **112** are prepared. A ceramic material that serves as the material of the ceramic multilayer substrate **112** has a composition mainly containing Ba, Al, and Si. Raw materials are prepared and mixed so as to achieve a predetermined composition and calcined at 800° C. to 1000° C. The resultant calcined powder is pulverized with a zirconia-ball mill for 12 hours to provide a ceramic powder. This ceramic powder is mixed with an organic solvent such as toluene or EKINEN, and further mixed with a binder and a plasticizer to provide a slurry. The thus-obtained slurry is formed by the doctor blade technique to provide ceramic green sheets that have a thickness of 50 μm and are to serve as the first to fourth insulating layers **131** to **134**.

An electrode paste for forming the first to third in-plane connecting conductors **114**a, **114**b, and **116** and the first and second interlayer connecting conductors **117**a and **117**b is also prepared. A solvent is added to 80 wt % of a Cu powder having an average particle size of about 1.5 μm and a binder resin containing ethyl cellulose or the like. The resultant substance is stirred and mixed with a roll to provide the electrode paste.

A mixture paste for forming the first and second mixture portions **120**a and **120**b is also prepared. The mixture paste is obtained by preparing an Al_2O_3-coated Cu powder having an average particle size of about 2 μm and, as a semiconductor material, silicon carbide (SiC) having an average particle size of 1 μm to achieve predetermined proportions; by adding a binder resin and a solvent to the resultant substance; and by stirring and mixing the resultant substance with a roll. The mixture paste contains 20 wt % of the binder resin and the solvent, and the remainder, 80 wt % of the Al_2O_3-coated Cu powder and silicon carbide.

In the ceramic green sheets that are to serve as the second and third insulating layers **132** and **133**, via holes are formed so as to extend through the main surfaces of the ceramic green sheets with laser or a mold. The via holes are then filled with the mixture paste by screen printing to form portions that are to serve as the first and second interlayer connecting conductors **117**a and **117**b.

The mixture paste is then applied to the ceramic green sheets that are to serve as the second and third insulating layers **132** and **133** by screen printing to form portions that are to serve as the first and second mixture portions **120**a and **120**b. The portion that is to serve as the first mixture portion **120**a may be formed on the ceramic green sheet that is to serve as the first insulating layer **131**. The portion that is to serve as the second mixture portion **120**b may be formed on the ceramic green sheet that is to serve as the second insulating layer **132**.

The electrode paste is then applied to the ceramic green sheets that are to serve as the second to fourth insulating layers **132**, **133**, and **134** by screen printing to form portions that are to serve as the first to third in-plane connecting conductors **114**a, **114**b, and **116**. The portion that is to serve as the first in-plane connecting conductor **114**a may be formed on the ceramic green sheet that is to serve as the first insulating layer **131**. The portion that is to serve as the second in-plane connecting conductor **114**b may be formed on the ceramic green sheet that is to serve as the second insulating layer **132**. The portion that is to serve as the third in-plane connecting conductor **116** may be formed on the ceramic green sheet that is to serve as the third insulating layer **133**.

After the portions that are to serve as the first to third in-plane connecting conductors **114**a, **114**b, and **116** are formed, the portions that are to serve as the first and second mixture portions **120**a and **120**b may be formed.

When a hollow is formed so as to be in contact with the mixture portions **120**a and **120**b, a main surface of the first in-plane connecting conductor **114**a, a main surface of the second in-plane connecting conductor **114**b, and the outer periphery or an end surface of the first interlayer connecting conductor **117**a, a resin paste that can be eliminated (such as an acrylic paste or a carbon paste) is applied by screen printing onto the previously formed portions that are to serve as the mixture portions **120**_a_ and **120**_b_ and the in-plane connecting conductors **114**_a_ and **114**_b_.

As with the standard ceramic multilayer substrates, the ceramic green sheets are laminated and press-bonded.

As with chip-type electronic components such as LC filters, the resultant laminated body is cut with a microcutter into chips. After that, the electrode paste is applied to the end surfaces of the chips to form the outer terminals.

As with the standard ceramic multilayer substrates, the chips are then fired in N_2 atmosphere. In the case of using an electrode material that is not oxidized (such as Ag), the firing may be performed in the air atmosphere. The firing causes elimination of the organic solvent in the ceramic green sheets and the binder resin and the solvent in the mixture paste. As a result, the first and second mixture portions **120**_a_ and **120**_b_ in which Al_2O_3-coated Cu, SiC, and cavities are dispersed are formed.

As with chip-type electronic components such as LC filters, the outer terminals are electrolytically plated with Ni—Sn.

Thus, the ESD protection device **110** having a section illustrated in FIG. **11** has been completed.

The semiconductor material is not particularly limited to the above-described material. Examples of the semiconductor material include semiconductors of metals such as silicon and germanium; carbides such as silicon carbide, titanium carbide, zirconium carbide, molybdenum carbide, and tungsten carbide; nitrides such as titanium nitride, zirconium nitride, chromium nitride, vanadium nitride, and tantalum nitride; silicides such as titanium silicide, zirconium silicide, tungsten silicide, molybdenum silicide, and chromium silicide; borides such as titanium boride, zirconium boride, chromium boride, lanthanum boride, molybdenum boride, and tungsten boride; and oxides such as zinc oxide and strontium titanate. In particular, silicon carbide and zinc oxide are preferred because they are relatively inexpensive and products having various particle sizes are commercially available. Such semiconductor materials may be properly used alone or in combination of two or more thereof. Such a semiconductor material may be properly used in the form of a mixture with an insulating material such as alumina or a BAS material.

The metal material is not particularly limited to the above-described material. Examples of the metal material include Cu, Ag, Pd, Pt, Al, Ni, W, and Mo, alloys of the foregoing, and combinations of the foregoing.

Fourth Preferred Embodiment

An ESD protection device **110**_a_ according to a fourth preferred embodiment will be described with reference to FIGS. **14** and **15**.

FIG. **14** is a sectional view of the ESD protection device **110**_a_ according to the fourth preferred embodiment. As illustrated in FIG. **14**, the ESD protection device **110**_a_ according to the fourth preferred embodiment has substantially the same configuration as the ESD protection device **110** according to the third preferred embodiment. Hereinafter, like reference signs in the third preferred embodiment will be used to denote like elements and differences from the third preferred embodiment will be mainly described.

As illustrated in FIG. **14**, the ESD protection device **110**_a_ according to the fourth preferred embodiment includes, in addition to the configuration of the third preferred embodiment, sealing layers **122** and **124** disposed between the first mixture portion **120**_a_ and the first and second insulating layers **131** and **132**, and sealing layers **126** and **128** disposed between the second mixture portion **120**_b_ and the second and third insulating layers **132** and **133**. The sealing layers **122**, **124**, **126**, and **128** significantly reduce and prevent permeation of a glass component in the ceramic multilayer substrate **112** into the first and second mixture portions **120**_a_ and **120**_b_. Each of the sealing layers **122**, **124**, **126**, and **128** has an insulating property.

As illustrated in sectional views in FIG. **15**A to **15**Dd, such a configuration can be produced by forming, laminating, press-bonding, and firing the ceramic green sheets that are to serve as the first to fourth insulating layers **131** to **134**.

As illustrated in FIGS. **15**B and **15**C, in the ceramic green sheets that are to serve as the second and third insulating layers **132** and **133**, the via holes **132**_p_ and **133**_p_ are formed. The via holes **132**_p_ and **133**_p_ are filled with the electrode paste to form portions that are to serve as the first and second interlayer connecting conductors **117**_a_ and **117**_b_.

Subsequently, as illustrated in FIG. **15**A to **15**C, a paste for forming the sealing layers is applied by screen printing and then dried. Thus, the sealing layers **122**, **124**, **126**, and **128** are formed on opposing surfaces **131**_t_, **132**_s_, **132**_t_, and **133**_s_ of the ceramic green sheets that are to serve as the first to third insulating layers **131** to **133**.

Subsequently, as illustrated in FIGS. **15**B and **15**C, the mixture paste is applied by screen printing onto the sealing layers **124** and **128** on the ceramic green sheets that are to serve as the second and third insulating layers **132** and **133**, to thereby form portions that are to serve as the first and second mixture portions **120**_a_ and **120**_b_.

Subsequently, as illustrated in FIG. **15**B to **15**D, the electrode paste is used to form the first to third in-plane connecting conductors **114**_a_, **114**_b_, and **116** on the ceramic green sheets that are to serve as the second to fourth insulating layers **132** to **134**.

Alternatively, the portions that are to serve as the first and second mixture portions **120**_a_ and **120**_b_ and the portions that are to serve as the first to third in-plane connecting conductors **114**_a_, **114**_b_, and **116** may be formed on the opposite side, that is, the ceramic green sheets that are to serve as the first to third insulating layers **131** to **133**.

After the portions that are to serve as the first to third in-plane connecting conductors **114**_a_, **114**_b_, and **116** are formed, the portions that are to serve as the first and second mixture portions **120**_a_ and **120**_b_ may be formed.

The paste for forming the sealing layers **122**, **124**, **126**, and **128** is prepared in the same manner as in the electrode paste. For example, a solvent is added to 80 wt % of an Al_2O_3 powder having an average particle size of about 1 μm and a binder resin containing ethyl cellulose or the like; the resultant substance is stirred and mixed with a roll to provide the paste (alumina paste) for forming the sealing layers. The solid component of the paste for forming the sealing layers is selected from materials having a higher sintering temperature than the material of the ceramic multilayer substrate, such as alumina, zirconia, magnesia, mullite, and quartz.

As described above, by making at least one of the discharge electrodes be an interlayer connecting conductor, the reliability of the ESD protection function can be enhanced. In addition, desired ESD responsivity can be easily achieved.

The present invention is not limited to the above-described preferred embodiments and encompasses various modifications.

For example, the case in which the ESD protection device is a single component (ESD protection device) having an ESD protection function only has been described as an example. Alternatively, the ESD protection device may be, for example, a composite component (module) having the

ESD protection function and another function. When the ESD protection device is, for example, such a composite component (module), it at least includes an interlayer connecting conductor, the first and second mixture portions connected to the interlayer connecting conductor, and another connecting conductor (in-plane connecting conductor or another interlayer connecting conductor) connected to the first and second mixture portions.

The mixture portions and connecting conductors may be formed on the surface of the ceramic multilayer substrate. In this case, the mixture portions and connecting conductors that are exposed on the surface of the ceramic multilayer substrate are preferably covered with a cover layer having an insulating property or covered with cover members that are separated from each other.

While preferred embodiments of the present invention have been described above, it is to be understood that variations and modifications will be apparent to those skilled in the art without departing from the scope and spirit of the present invention. The scope of the present invention, therefore, is to be determined solely by the following claims.

What is claimed is:

1. An ESD protection device comprising:

a ceramic multilayer substrate including a plurality of ceramic insulating layers laminated on each other;

a first connecting conductor that has electrical conductivity and completely fills a via hole which penetrates through at least one of the plurality of ceramic insulating layers;

a mixture portion that extends along one of the main surfaces of the at least one of the plurality of ceramic insulating layers including the first connecting conductor and is connected to the first connecting conductor, the mixture portion including a material dispersed therein, the material including at least one selected from (i) a metal and a semiconductor, (ii) a metal and a ceramic, (iii) a metal, a semiconductor, and a ceramic, (iv) a semiconductor and a ceramic, (v) a semiconductor, (vi) a metal coated with an inorganic material, (vii) a metal coated with an inorganic material and a semiconductor, (viii) a metal coated with an inorganic material and a ceramic, and (ix) a metal coated with an inorganic material, a semiconductor, and a ceramic; and

a second connecting conductor that has electrical conductivity, is separated from the first connecting conductor, is connected to the mixture portion, and extends along the main surface of the at least one of the plurality of ceramic insulating layers on which the mixture portion is provided.

2. The ESD protection device according to claim **1**, wherein

the second connecting conductor extends along the main surface of the at least one of the plurality of ceramic insulating layers on which the mixture portion is provided, surrounds an outer periphery of the mixture portion, and is electrically connected to the outer periphery of the mixture portion; and

the first connecting conductor is concentric with the mixture portion, extends through the main surfaces of the at least one of the plurality of ceramic insulating layers, and is electrically connected to the mixture portion so as to be separated from the outer periphery of the mixture portion.

3. The ESD protection device according to claim **1**, wherein a hollow portion is in contact with the mixture portion and a main surface of the second connecting conductor.

4. The ESD protection device according to claim **1**, wherein the first connecting conductor is directly connected to the mixture portion.

5. The ESD protection device according to claim **1**, wherein

an opening is defined in a center of the mixture portion;

the ESD protection device further comprises a third connecting conductor that has electrical conductivity, extends along the main surface of the at least one of the plurality of ceramic insulating layers on which the mixture portion is formed, and is connected to an periphery of the opening of the mixture portion; and

the first connecting conductor is connected to the third connecting conductor.

6. The ESD protection device according to claim **1**, wherein, in the mixture portion, a metal material and a semiconductor material are dispersed.

7. The ESD protection device according to claim **6**, wherein the semiconductor material is silicon carbide or zinc oxide.

8. The ESD protection device according to claim **1**, wherein, in the mixture portion, a metal material coated with an insulating inorganic material is dispersed.

9. The ESD protection device according to claim **1**, further comprising a sealing layer disposed between the at least one of the plurality of ceramic insulating layers and the mixture portion and/or between the at least one of the plurality of ceramic insulating layers and the hollow portion, so as to extend along at least one of the plurality of ceramic the insulating layers.

10. The ESD protection device according to claim **1**, wherein a hollow is in contact with the first connecting conductor, the mixture portion, and the second connecting conductor.

11. The ESD protection device according to claim **10**, wherein, in the mixture portion, a metal material and a semiconductor material are dispersed.

12. The ESD protection device according to claim **11**, wherein the semiconductor material dispersed in the mixture portion is silicon carbide or zinc oxide.

13. The ESD protection device according to claim **1**, wherein, in the mixture portion, metal material particles coated with an insulating inorganic material are dispersed.

14. The ESD protection device according to claim **1**, further comprising a sealing layer disposed between the insulating layer and the mixture portion and/or between the at least one of the plurality of ceramic insulating layers and the hollow, so as to extend along the at least one of the plurality of ceramic insulating layers.

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